

EVALUATION OF IN SITU STABILISATION FOR BEST VALUE MANAGEMENT OF UNSEALED ROADS

Bob ANDREWS and Kieran SHARP

ARRB Group Ltd

500 Burwood Highway, Vermont South, Victoria, Australia

bob.andrews@arrb.com.au

ABSTRACT

The Australian road network consists of over 500,000 km of unsealed roads, or about 60% of the total road network. Approximately A\$1 billion is spent annually on maintaining this network. Maintenance cost per kilometre are high; unsealed roads are also the largest consumer of natural materials in the infrastructure industry. Any contribution to reducing these two prime factors will have a significant effect on triple-bottom-line considerations (i.e. cost, environment and social factors). This paper describes the evaluation of in situ stabilisation of unsealed roads in remote locations. Issues addressed include material availability and deficiency, construction logistics, binder selection, pavement performance and economic evaluation. Whilst no comparisons are made regarding the performance of each product, the paper presents a rational approach to the evaluation of material selection, processing and improvement in order to provide best value management of unsealed road networks. Some statistics regarding the prevalence of unsealed roads in the region are also presented.

1 INTRODUCTION

The Australian road network consists of over 500,000 km of unsealed roads, or about 60% of the total road network. Approximately A\$1 billion is spent annually on maintaining this network. Maintenance cost per kilometre are high; unsealed roads are also the largest consumer of natural materials in the infrastructure industry. Any contribution to reducing these two prime factors will have a significant effect on triple-bottom-line considerations (i.e. cost, environment and social factors).

This paper describes the evaluation of in situ stabilisation of unsealed roads in remote locations. Issues addressed include material availability and deficiency, construction logistics, binder selection, pavement performance and economic evaluation.

Some statistics regarding the prevalence of unsealed roads in the region are also presented.

2 NETWORK FUNCTION AND CHARACTERISTICS

The unsealed road network serves the community by providing:

- access to rural communities, often in isolated locations
- routes for the transport of livestock and support for the freight and agricultural industries
- routes supporting service to local communities
- haul roads for the mining and timber industries
- recreational, social and tourist pursuits
- emergency services access (e.g. fire fighting and protection) in national parks, etc.

Compared to sealed roads, the performance of unsealed road is typified by:

- high operating costs associated with surface maintenance and replenishment
- restricted, or no, access in times of heavy rain

- high accident risk associated with the presence of corrugations, pot-holes, dust, slippery surfaces (when wet) and loose dry surfaces
- a high environmental and heritage impact associated with the high consumption of natural materials and underground water supplies.

The stabilisation of unsealed road surface seeks to provide improvements to the network in terms of:

- safe operation – skid resistance and safe braking with less loose gravel on the road and increased visibility associated with reduced dust levels
- maintenance intervention – optimising the amount of routine patrol grading required to maintain an adequate riding surface and periods between re-surfacing
- reduced environment and heritage impact resulting from reduced material extraction and reduced impact of dust on the roadside habitat.

3 PREVALENCE OF UNSEALED ROADS IN THE REGION

Unsealed roads represent a significant proportion of the road network in many countries in the region. A comparison of the length of sealed and unsealed roads in various countries in the region (Table 1) reveals that 42.3%, or over 1.3 million kilometres, of the roads in the region are unsealed. The proportion of unsealed roads obviously varies between countries, from 0% in Singapore to 97% in Papua New Guinea. Other countries which have a proportion of unsealed roads over 50% include the Philippines (90%), Vietnam (81%), and Australia (58%), while other countries such as Indonesia, New Zealand, Brunei, Korea and Japan also have a significant network of unsealed roads.

The reasons for the high proportion of unsealed roads also varies according to geography, climate area, and economics. Whatever the reasons, it is clear that the efficient and effective management of the unsealed road network is a significant issue in most countries in the region.

Table 1. Unsealed Roads in the Region
<https://www.cia.gov/library/publications/the-world-factbook/geos/AS.html>

Country	Length of Road			% Unsealed
	Total (km)	Sealed (km)	Unsealed (km)	
Australia	812,972	341,448	471,524	58
Brunei	3,650	2,819	831	23
Indonesia	391,009	216,714	174,295	45
Japan	1,197,000	949,100	247,900	21
Korea	103,029	80,642	22,387	22
Malaysia	98,721	80,280	18,441	17
New Zealand	93,576	61,564	31,012	33
Papua New Guinea	19,600	686	18,914	97
Philippines	200,037	19,804	180,233	90
Singapore	3,262	3,262	0	0
Taiwan	40,262	38,171	2,091	5
Thailand	180,053	n/a	n/a	
Vietnam	222,179	42,167	180,012	81
<i>Total*</i>	<i>3,185,297</i>	<i>1,836,657</i>	<i>1,347,640</i>	<i>42</i>

* Excluding Thailand; note, however, that about 100,000 km of roads are under local road administration.

4 INITIAL CONSIDERATIONS

In considering the addition of a stabilisation binder as an option, it is necessary to firstly determine the suitability of the material to be stabilised and explore options for its improvement. The various strategies include:

- blending material from another source or working the pit face to include or exclude strata as required
- importing suitable material from another source or commercial quarry operation
- particle size may be reduced by treatment in the pit or on the road bed using commercial 'rock buster' machines or static grid rollers; alternatively, it may be considered that, if a stabilising machine is to be used, aggregate breakdown may be achieved with this plant
- accept a lower performance level and hence a shorter wearing course life and increased patrol grading intervention requirements.

For each of the strategies a life cycle analysis can indicate the most economical options and also provides the option to include less tangible costs such as the social and economic impacts that may be incurred due to rough/dusty surfaces or road closures.

5 SUITABILITY OF NATURAL MATERIALS

In selecting a material specification for an unsealed pavement, attributes such as grading, plasticity and CBR are typically of a lower order than for sealed roads because of the need to use locally-available materials which are predominantly natural gravels. Whilst this is compensated for by the fact that traffic volumes are generally low, it should be noted that some unsealed roads, even with low traffic intensities, must serve as vital transport links which require higher levels of serviceability than might otherwise be considered.

The wearing course material needs to provide good wearing resistance; otherwise, there would be a high level of loose surface material, gravelly surfaces and corrugations. In addition, low permeability will reduce the likelihood of potholes, surface rutting and shoving and the related inaccessibility issues.

The properties which affect the behaviour of a pavement material depend upon its skeletal structure and the nature of the stone aggregate and fine soil matrix. The principal factors affecting the performance of materials in relation to unsealed roads are:

- stability in terms of CBR (soaked and unsoaked)
- resistance to wear
- impermeability
- workability and compaction.

5.1 Stability

Stability is the ability of a material to resist deformation, both vertically and laterally. Strength is an important component associated with the ability of a material to resist imposed stresses. Most common measures of strength involve an assessment of the shear strength of a material. This is governed by the degree of aggregate interlock (particle friction) and cohesion (bonding of fine soil). The strength depends principally on its moisture and void (compacted density) content. Typical strength determinations include laboratory CBR testing, field testing using the Clegg Impact Hammer (Figure 1) and, to a lesser degree, field deflection tests such as the Falling Weight Deflectometer (FWD) (Figure 2).



Figure 1: Clegg Impact Hammer



Figure 2: Falling Weight Deflectometer

Typical CBR values for unsealed road pavement layers are shown in Table 2. Note that these values are lower than those recommended for lightly-trafficked sealed pavements on account of the more frequent patrol grading of unsealed surfaces.

Table 2. Suggested CBR Values for Unsealed Road Pavement Layers

Pavement Layer	Typical CBR (soaked)
wearing coarse (gravel materials)	min. 40
base	min. 50
subbase	min. 30

Typical Clegg Impact Values (CIV) obtained using the standard 4.5 kg Clegg Impact Hammer for different materials are shown in Table 3.

Table 3. Typical Clegg Impact Values (CIV)

Base Strength	CIV
very high	>100
high	75-100
medium to high	55-74
low to medium	30-54
low	<30

5.2 Resistance to Wear

The wearing surface should be compacted to produce a tight surface in which the aggregate is held in place as strongly as possible by the fine soil matrix as it is exposed to both weather and traffic forces. As fines are worn away (through the generation of dust) the texture of the surface becomes coarse and the aggregate is loosened, resulting in a very gravelly surface as shown in Figure 3.



Figure 3. Loose material on pavement

5.3 Impermeability

A relatively impermeable surfacing material is required to protect the underlying material from the entry of water and subsequent loss of bearing strength or stability. Although permeability can be measured directly, it is usually inferred from classification and index tests.

Typical permeability values for 100% Standard compaction tested under falling head conditions, i.e. according to test method AS1289.6.7.2, are shown in Table 4.

Table 4. Indicative Permeability Values
(100% Standard Compaction)

Material	Suggested maximum permeability (m/s)
unsealed wearing course	1×10^{-4}
base and subbase	1×10^{-3}

5.4 Workability and Compaction

The workability of a material relates to the ease to which it can be compacted to a desired density and the nature of the finished surface in terms of tightness and uniformity (no segregated and bony areas). In addition, the moisture-density relationship can be used when considering the selection of a material in terms of the costs associated with the amount of water required to be brought to the site.

The shape of the dry density-moisture content parabola, in terms of being steep or flat, is an indication of the moisture sensitivity of a material and the moisture range in which the desired density can be achieved. A moisture content range of one-third of the OMC value either side of optimum is generally desirable.

6 STABILISATION PROTOCOL

In establishing the need for stabilisation and the incorporation of a stabilisation binder the following protocol has been developed to assist in the evaluation of a suitable binder and the methodology for monitoring pavement performance.

1. Desk top evaluation of product or process to be trialled in terms of its application logistics to the proposed site and previous trials and performance.
2. Simple laboratory evaluation to determine suitability of the product in relation to the site material. The results may indicate a hold point in the event that benefits are not realised or unjustified.
3. HOLD POINT to determine if a field trial is necessary.
4. Selection of field trial site based on local needs and environmental factors.
5. Preparation of a 'Scope of Works' document if construction is to be undertaken under contract.
6. Construction of trial site and development of quality control program.
7. Establishment of performance indicators which define the benefits of the product or the process for inception recommendations.
8. Application of a performance monitoring schedule.
9. Performance evaluation in terms of technical appraisal and deterioration modelling.
10. Financial modelling in terms of estimated pavement life and maintenance interventions.

6.1 Example of Protocol Application

A field test site was selected near Alice Springs in the Northern Territory, Australia, to trial the protocol and address the issue of a lack of a suitable wearing course crushed rock throughout a 200 km wide radius for the site of the unsealed road construction. As a result, most roads in the area are constructed directly on the silty-sand subgrade and, as such, require regular grading intervention, resulting in material depletion, high dust levels and frequent road closures.

6.1.1 Binder considerations

In situ stabilisation was selected as the only option available if the performance of the silty sand was to be improved. Consequently a field trial involving three binder combinations (two synthetic polymer products and hydrated lime) was developed.

The adoption of polymers was based on the fact that they impart hydrophobic properties to the soil, thereby maintaining dry strength and resulting in improved performance of the road surface.

Example laboratory demonstration tests can be conducted to evaluate the effectiveness of a particular binder using the vertical saturation test shown in Figure 4 [1].

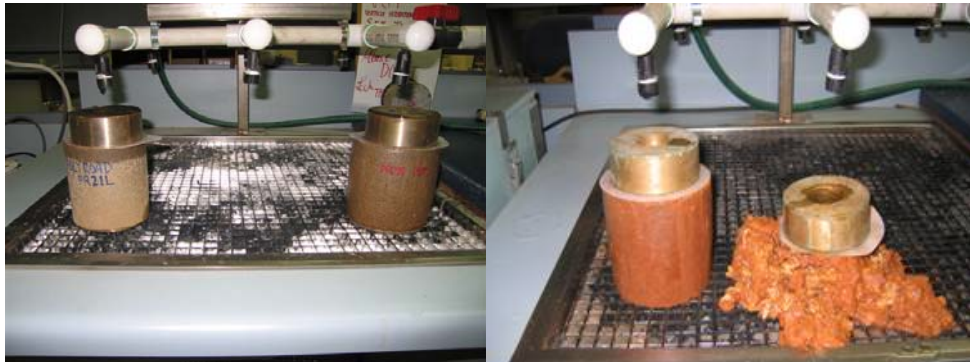


Figure 4. Example vertical saturation testing – product evaluation

The following products were evaluated.

Polyroad 21L

This product is a synthetic dry powder polymer (DPP) which has been widely used on the sealed network for over 15 years. Its performance is well documented through case studies, application protocols and Technical Note produced by the Australian Stabilisation Industry Association (AustStab) [2].

The P21L product is powder binder consisting of two parts polymer (the polymer being thermally bonded to a flyash carrier) and one part hydrated lime.

Polycom

This product is a synthetic polyacrylamide applied through a venturi system to the water as the water truck is being filled. The product has been used predominantly on unsealed roads throughout Australia; its performance is documented by technical appraisal reports and case studies.

Hydrated lime

Hydrated lime (or quicklime) was selected in order that the performance of the polymer products could be compared with that of a standard product used on large sections of the Australian network for over 80 years. Guidance to the most appropriate use of lime stabilisation is contained in Part 4D of the Austroads Guide to Pavement Technology [1].

6.1.2 Product Logistics

In selecting a binder it is necessary to consider logistics in terms of the following:

- Transport of the binder to site: In remote areas the use of a powder binder can require 25 tonnes per kilometre for 2% addition (by mass) for a pavement 8 metres wide and 150 mm thick. As a result, high transport costs may be involved.
- Construction equipment: The use of powder binders requires delivery by tanker or bulk bags and associated lifting equipment must be available. In addition, a binder spreader is required to evenly apply the product to the roadbed; grader spreading is not generally recommended.

However, the remoteness of a location often dictates that grader blade mixing is the only option available.

- **Product cost:** The construction cost using these binders can be as high as \$50,000 per kilometre. However, this is offset by the increase in the life of the wearing course before replenishment is needed, the fact that the road can be kept open for most of the year, and the reduction in the frequency of patrol grading intervention. Analysis using a life cycle cost model will demonstrate the overall cost advantages associated with the use of the binder and the additional items of plant.
- **Health and safety:** The lifting of bulker bags and the dropping of the fine powder binders into the spreader demands that the operator be protected from dust. In addition, some binders can burn (e.g. quicklime) and some are extremely acidic in their undiluted form. When the powder binders were used in the field trial in the Northern Territory, loading the binder from bulker bags proved difficult and hazardous and not particularly suited to construction in remote areas unless significant volumes of work are anticipated. The use of the venturi system with the polyacrylamide binder proved to be most efficient and more suited to remote location stabilisation.

6.1.3 Performance Monitoring

The periodic (preferably monthly) performance monitoring of the pavement is conducted as follows (see also Figure 5):

1. **Drive through:** rate the severity of loose material, corrugations, potholes and erosion channels which affect the rideability of the pavement (low / medium / high) which would necessitate maintenance intervention by patrol grading.
2. **Roughness:** undertake a physical pavement roughness assessment using the ARRB Roughometer or similar device to provide quantitative information regarding the development of pavement roughness.
3. **Surface wear:** sweep away the outer and centre windrow (between the outer and inner wheelpaths) in order to bed a 3 metre straight edge on a hard surface and measure the rut depths in both wheelpaths. Use this data to estimate the resurfacing (resheeting) intervals.
4. **Ravelling:** use a 3 metre straight edge, located in the longitudinal direction, and measure outer windrow heights (Figure 6). This provides an indication of the amount of material being ravelled out of the pavement.
5. **Loose material:** mark a one metre square area centrally over the centre windrow (between the outer and inner wheelpaths), remove the loose material by sweeping, place it in a bag and retain for future evaluation. Clearly tag the location from which the sample was taken.
6. **Take a full photographic record of the site, including the testing protocols.**
7. **Note weather information on the day of monitoring; access rainfall records from the nearest meteorology station; install a traffic counter (e.g. pneumatic counter) to record traffic volumes.**

It is important that the pavement cross-sections are clearly identified and marked as monitoring locations to ensure that measurements are always taken at the same location (Figure 7). This ensures some consistency in the data and assists in the identification of photographs, etc.

The following information should also be recorded:

- locations close to trail section boundaries: each section may have different performance attributes, e.g. dust transfer at trail section boundaries
- drainage channels and culverts
- bends where shear forces are significant in terms of promoting greater material loss.

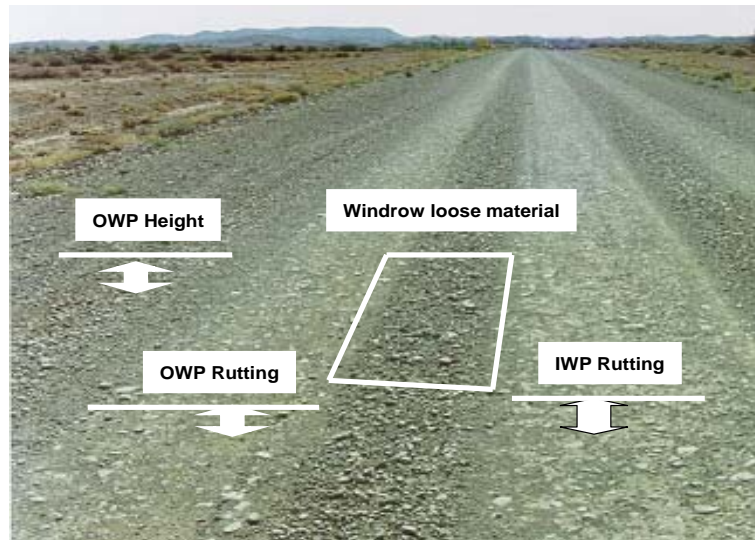


Figure 5. Performance deterioration attributes



Figure 6. Measurement of rutting, and windrow development



Figure 7. Site signage

The adoption of this visual method, together with the elementary quantitative measurements, will provide a monitoring platform for the assessment of the protocol. It is important that sufficient budget, and time, is provided to enable the collection of sufficient data to allow trends to be properly evaluated.

An example of the change in pavement condition over a period of three months is in Figure 8 and Figure 9.



Figure 8. Pavement deterioration, February-May 2009



Figure 9. Pavement deterioration, February-May 2009 (stabilised section)

6.1.4 Economic life cycle assessment

To evaluate the relative cost effectiveness of the various products trialled an economic life cycle analysis is required. An example used in Australia is the life cycle costing system developed by the Roads & Traffic Authority, NSW. In this system, the Net Present Worth (NPW) and the Equivalent Annual Cash Flow (EACF) defined by the following formulae:

$$NPW = \sum \$C_n \left[\frac{1}{(1+r)^n} \right] \quad \text{and} \quad EACF = NPW \left[\frac{r(1+r)^N}{(1+r)^N - 1} \right]$$

- where
- $\$C_n$ = treatment cost in year 'n'
 - r = discount rate of future expenditure
(taken as 6%, including net effects of inflation)
 - n = number of years projected into the future
 - N = life of the strategy.

An estimate of the life of the wearing course before replenishment and grading intervention is assumed, determined from current gravel loss analyses [3], or from estimates based on performance monitoring using the protocol.

The analysis can also include all costs associated with the various scenarios, viz:

- blending materials
- treatment of material on the roadbed with rock-busters or grid rollers
- sourcing material from elsewhere, resulting in higher transport costs which can also be traded against avoiding road closures or major reconstruction after flooding
- additional costs associated with stabilisation, i.e. costs of binder and specialised equipment
- whether providing a bituminous chip seal is appropriate.

An example analysis relating to the relationships between the life of the wearing course prior to replenishment and patrol grading intervention is shown in Figure 10 and Figure 11.

Year	Activity	Sheeting Cost	Stabilisation Binder Cost	Grading Intervention	Patrol grading cost	Discount Rate	Analysis period	Annual NPW	Net Present Worth	Equivalent Annual Cash Flow
0	Resheet	\$25,000		6 months	\$150	0	20	25150	39303	3427
1	Patrol grade				\$150	0.06		133		
2	Patrol grade			Sheeting Life	\$150	0.06		126		
3	Patrol grade			10 years	\$150	0.06		119		
4	Patrol grade				\$150	0.06		112		
5	Patrol grade				\$150	0.06		106		
6	Patrol grade				\$150	0.06		100		
7	Patrol grade				\$150	0.06		94		
8	Patrol grade				\$150	0.06		89		
9	Patrol grade				\$150	0.06		84		
10	Patrol grade				\$150	0.06		79		
11	Resheet	\$25,000			\$150	0.06		12499		
12	Patrol grade				\$150	0.06		70		
13	Patrol grade				\$150	0.06		66		
14	Patrol grade				\$150	0.06		63		
15	Patrol grade				\$150	0.06		59		
16	Patrol grade				\$150	0.06		56		
17	Patrol grade				\$150	0.06		53		
18	Patrol grade				\$150	0.06		50		
19	Patrol grade				\$150	0.06		47		
20	Patrol grade				\$150	0.06		150		

Figure 10. Example life cycle analysis

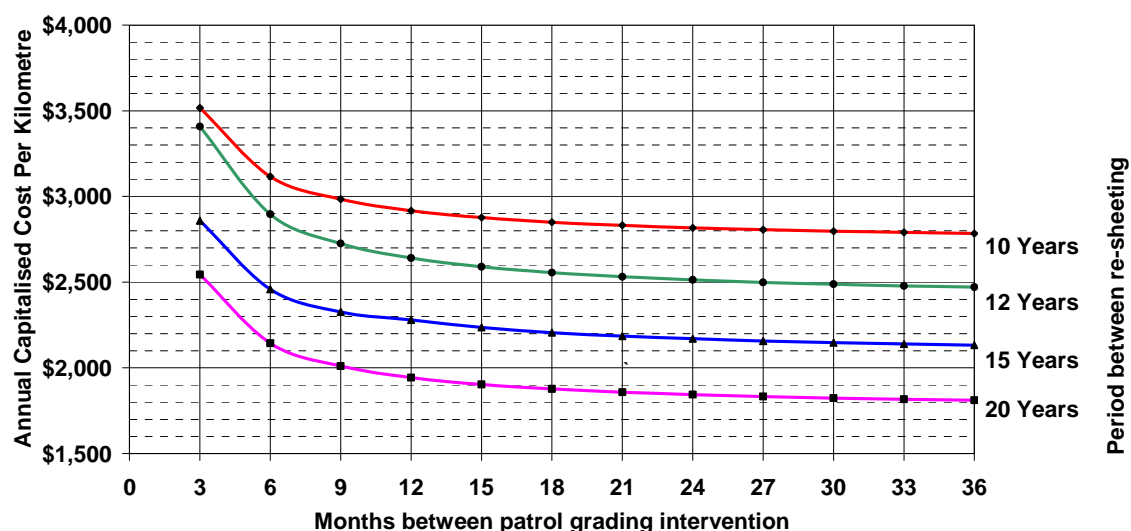


Figure 11. Analysis of patrol grading and wearing course life

In this simple scenario analysis it can be seen that increasing grading intervention frequencies beyond 12 months had little impact on life cycle costs. On the other hand, the benefit of increasing sheeting life was very significant. Therefore any process, e.g. blending materials or stabilisation that increases sheeting life, can have a significant cost benefit even though the initial prime costs are greater.

7 SUMMARY

This paper has described the evaluation of in situ stabilisation of unsealed roads in remote locations. Issues addressed include material availability and deficiency, construction logistics, binder selection, pavement performance and economic evaluation.

Whilst no comparisons are made regarding the performance of each product, the paper has illustrated a rational approach to selecting the best material available and consideration of stabilisation where its properties can be improved.

When considering a stabilisation binder, there are a myriad of products available and a simple approach to evaluation through the vertical saturation test can illustrate their effectiveness prior to embarking on expensive and often poorly-managed field trials.

Performance monitoring has been based upon simple tools which enable measurements and observations to be undertaken by local authorities/communities.

The life cycle analysis also allows a rational economic consideration of various options, including the construction process adopted, the materials selected and the socio-economic implications of a poor or inaccessible road.

REFERENCES

1. Austroads, Guide to pavement technology – Part 4D, Stabilised materials, 2009.
2. AustStab, Stabilisation using dry powdered polymers. Technical Note 3, <http://www.auststab.com.au/>, 2003.
3. Austroads, Guide to pavement technology – Part 6, Unsealed pavements, 2009.